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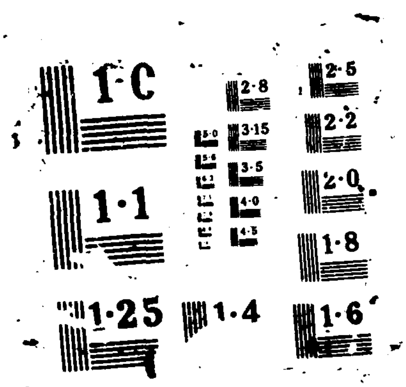
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In August, 1986, the U.S. Army Engineer Topographic Laboratories (USAETL) began a three-year program to introduce the use of Global Positioning Systems (GPS) technology to all U.S. Army Corps of Engineers Districts and Divisions as a means of performing geodetic surveys. Through this program, district survey personnel have the opportunity to participate in a survey project of the district's choice. USAETL purchased six GPS receivers to be used in a series of demonstrations in this program. Both during and after each demonstration, feedback is being fiven by district personnel on items such as how field operations could be changed, how the equipment could be modified to make it more user friendly, and most importantly, how GPS could be applied to assist them in performing their survey mission.

Although relative static GPS offers a substantial improvement over the way many conventional surveys are performed, district personnel indicated that many applications are not feasible at present because of the time needed to conduct observations at each monument. Since 1985, there has been growing interest in reducing the observation time required to perform geodetic

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surveys with GPS. One method of reducing the observation time is a technique referred to as relative kinematic surveying.

This paper will examine the techniques of relative static and relative kinematic surveying and discuss the benefits of each. Examples of applicaitons in which each technique could prove beneficial for the Corps surveyor, such as dam monitoring, will be presented.

A COMPARISON: STATIC AND FUTURE KINEMATIC GPS SURVEYS[a]

By Kevin P. Logan[1]

INTRODUCTION

In August, 1986, the U.S. Army Engineer Topographic Laboratories (USAETL) began a three-year program to introduce the use of Global Positioning System (GPS) technology to all U.S. Army Corps of Engineers Districts and Divisions as a means of performing geodetic surveys. Through this program, district survey personnel have the opportunity to participate in a survey project of the district's choice. USAETL purchased six GPS receivers to be used in a series of demonstrations in this program. Both during and after each demonstration, feedback is being given by district personnel on items such as how field operations could be changed, how the equipment could be modified to make it more user friendly, and most importantly, how GPS could be applied to assist them in performing their survey mission.

Although relative static GPS offers a substantial improvement over the way many conventional surveys are performed, district personnel indicated that many applications are not

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feasible at present because of the time needed to conduct observations at each monument. Since 1985, there has been growing interest in reducing the observation time required to perform geodetic surveys with GPS. One method of reducing the observation time is a technique referred to as relative kinematic surveying.

This paper will examine the techniques of relative static and relative kinematic surveying and discuss the benefits of each. Examples of applications in which each technique could prove beneficial for the Corps surveyor, such as dam monitoring, will be presented.

RELATIVE STATIC GPS

The use of GPS in the relative static mode allows the Corps surveyor to perform many surveys more efficiently than by conventional methods. This results in savings of time and money. The amount of savings depends on the size and type of survey.

To obtain the highest precision from GPS, two or more receivers are used in the relative static mode. In this mode, each receiver occupies a different monument and measurements are obtained from the same four or more satellites simultaneously for 1/2 to 2 hours, depending on the precision required. The higher the precision and the longer the distance between the monuments, the longer the observation period.

These measurements are then brought together at a central location and post-processed to determine the 3-dimensional (3-D) relative vector between two monuments. These vectors are then applied to known reference monuments to determine the positions of unknown monuments.

There are different techniques of tracking the satellite signals in order to obtain the information needed to determine the baseline vector between two monuments. The Corps of Engineers currently uses the technique of tracking the L1 carrier signal. The Course/Acquisition or C/A code is modulated on this L1 carrier signal. By receiving the C/A code, the ground receiver's absolute position can be determined to approximately 15 meters at this time. Obviously, this accuracy is not sufficient to meet precise geodetic survey requirements. By tracking the carrier signal and using the GPS in a relative static mode, accuracies of 1- to 2-parts-per-million (ppm) can be obtained routinely in determining baseline vectors on lines less than 50 km in length. If distances between monuments exceed 50 km, it is necessary to use a dual frequency receiver to solve for signal delays caused by the ionosphere.

Many GPS receivers available today are capable of measuring the carrier signal phase from 1 to 2 mm. These measurements are ambiguous because the whole number of cycles from the satellite to the receiver is unknown (integer cycle ambiguity). By recording simultaneous observations at multiple stations for 1/2 to 2 hours, sophisticated signal differencing

techniques may be employed for processing data. These techniques allow the elimination of several error sources and the resolution of the integer cycle ambiguity. The final result is a baseline vector between two monuments at the precision required for geodetic surveys.

It is important to remember that using GPS in the relative static mode is not feasible for every survey. Because of the time required for observations at each monument, it would not be feasible, for example, to use GPS to perform surveys which only require traversing over short distances and which present no problems with line of sight between monuments. These surveys could be done much more efficiently with conventional methods.

The use of GPS would prove beneficial in the following applications: 1) establishing control in an area where no other known control is within traversing distance, 2) checking the known control monuments to be used on a project, 3) continuous monitoring of movement of large structures, and 4) subsidence monitoring. Conventional survey methods either do not perform these tasks in the most efficient manner or cannot perform them at all. For example, it is impossible to check the known control in relation to the other control monuments.

The following is an example of a project just completed by the Louisville District where control to be used with aerial photography was established. The mapping project was relatively small, consisting of two adjoining flight lines with

five models in each, totaling 10 models. The topography of the area is rolling hills with narrow country roads branching off two main highways. Seven horizontal and vertical points were selected to analytically control the two flight lines.

The government time estimate for establishing this control using conventional methods was 10 days, including 8 days for a three-person party to perform the field work, and 2 days for one person to complete the data reduction.

The actual time involved to complete this project by using two GPS receivers in the relative static mode was 4 days. After one person spent 1 day completing the field reconnaissance, a two-person GPS party needed only 3 days to complete all data collection and data processing. All information including a final summary of the State Plane Coordinates along with the project report were recorded on a floppy disk in the field. This meant that when the field work was completed and personnel returned to the district office, the entire project through final report was complete. Using GPS in the relative static mode reduced the time required to complete this project from 10 days to 4 days.

One problem with using GPS for establishing photo control is that the antenna cannot always be set over the natural targets selected for photo identifiable points. A GPS station was set as close to the natural targets as possible for full view to the satellites. Sun shots and taped distances were made to transfer horizontal positions from GPS stations to

the photo points. Level ties were made to transfer elevations from GPS stations to vertical photo points. These sun observations, level ties and references were done during the day by the same personnel performing GPS work, while GPS observations were made during the available observation window at night.

One big advantage of GPS over conventional survey methods is that GPS is an all-weather system. Successful GPS observations have been performed in adverse conditions, such as snow storms, rain and sub-freezing temperatures. However, experience has shown that satellite data gathered during electrical storms is generally useless.

RELATIVE KINEMATIC GPS

In 1985, the National Geodetic Survey (NGS), which was already performing centimeter-accuracy relative static surveys using GPS, recognized the same problem with GPS that was being recognized by the Corps surveyors. GPS can be a production tool for performing many surveys, especially for baselines longer than 10 km, but GPS is not feasible to use on shorter baselines such as 500 meters. This provided the interest for a test to be performed to see if centimeter-accuracies could be obtained in seconds by measuring the carrier phase (Remondi, 1985). This test verified the potential to perform this type of survey in a production mode.

Engineers at USAETL have been very interested in performing centimeter-accuracy surveys with GPS since the test by Remondi in 1985. Feedback from the Corps surveyors has confirmed the need for this. Shortly after taking delivery of GPS receivers, USAETL began discussions on performing a relative kinematic survey test. It was decided to perform this test with commercially available C/A code receivers, since these are the type of instruments the Corps surveyors would be using on a regular basis.

Relative Kinematic Surveying, as referred to in this paper, is the determination of the 3-D vectors between a reference monument and a series of unknown monuments. This is done by locating a GPS receiver at a reference monument while another GPS receiver (rover) moves through a series of unknown monuments. Both receivers track the same satellites simultaneously as in relative static surveying. The receiver located at the reference monument continues to track satellites until the rover has occupied all unknown monuments. The roving receiver moves from monument to monument, maintaining lock on satellites. At each unknown monument, the rover remains static for a few minutes (<5).

In order to obtain centimeter-level vectors, the integer biases have to be determined before the rover can begin moving from monument to monument. Two receivers must occupy a baseline for a period long enough to determine these biases. Over short baselines, this usually can be done successfully in 45

minutes. Once ample data have been recorded to solve for the biases, the antenna can be moved from that monument to the next monument. The most important thing to remember is that lock has to be maintained on the satellite signal during movement for the biases to be used in the computations of the vector for the next unknown monument. If loss of lock occurs, and a sufficient number of satellites are not being tracked to maintain the initial integer biases, initialization procedures have to be performed again to obtain the integer biases (Goad, 1987).

The area of dam monitoring is an application where USAETL personnel believe that using GPS in the relative kinematic survey mode could prove beneficial. Currently, many districts monitor dams and structures for movement. The number of dams and structures monitored vary from district to district and many different methods are used throughout the Corps for this task, depending on the dam or structure. In one district, an alignment type survey is done in conjunction with conventional levels. On larger dams, where topography will allow, trilateration is performed for horizontal movement and conventional levels are used for vertical movement. On many dams, because of the topography, it is not possible to establish a strong inner-braced quadrilateral for a control scheme. One particular case is the Uniontown Locks and Dam in the Louisville District. Because the area around this structure is lower than the structure itself, there is no intervisibility between control

monuments and the dam. The district is considering using observation towers to provide line of sight, but is also exploring other methods to solve this problem. One advantage that GPS would have over conventional trilateration at this site is that control monuments would not have to be intervisible.

There are about 110 monitoring points located throughout the structure at the Uniontown Locks and Dam. It is virtually impossible to provide a strong control network to all of these points with each point visible to at least three control monuments. Currently, optical alignments are made at night and conventional levels run to monitor the structure. At best, horizontal repeatability is 1 centimeter. Although optical alignments are made in two directions, from each end of the line, experience has shown that these lines are "refracted."

The time involved to complete alignments and levels at Uniontown Locks and Dam is normally 10 days. A three-person party spends 8 days in data collection. After the field work is completed, one office technician needs 2 additional days for data reduction.

In contrast, the estimated time to establish vectors to all 110 points at this site using GPS in the relative kinematic mode is only 2 days for a three-person party. Again, it is possible that much of the data reduction and initial report preparation could be accomplished on-site. This estimate is based on an 8-hour observation window using three receivers, two on known reference monuments and one rover on the dam.

The receivers at the reference monuments will track satellites continuously while the rover is moving from monument to monument. The rover will occupy each monument for 3 minutes with 5 minutes travel time between monuments.

An assumption is made in this estimate that loss of lock does not occur while the rover is moving. If loss of lock occurs, initialization procedures may have to be performed again to solve for the integer biases. As explained previously, this problem may be avoided by tracking a sufficient number of satellites. Two receivers will be used on known reference monuments, creating a closed loop for the verification of raw measurements. This procedure will avoid the problems which would occur if only one receiver was used at a known reference monument, making it impossible to check raw measurements. Using only one reference monument would be similar to a side shot.

The advantage that GPS offers on the Uniontown project is that it can solve the intervisibility problem presented by the conventional survey methods, and can allow the project to be completed much more efficiently.

TESTING

In early 1987, a demonstration of the use of GPS for performing relative static surveys was planned for the Corps of Engineers Kansas City District. After discussions with

district personnel, two sites were chosen: the Clinton Lake Dam near Lawrence, Kansas and another location south of Lawrence where control was needed for conventional surveys.

The demonstration at Clinton Lake Dam had two objectives: to compare GPS, when used in the relative static mode, to conventional techniques that are currently used to monitor movement; and to test GPS in the kinematic survey mode against conventional methods. Clinton Lake Dam was an ideal structure for the relative kinematic test because of the layout of the monuments and the force centering devices already installed at each monument.

The dam is approximately 3,000 meters long and has 42 monitoring points located across the crest of the dam. There are four control monuments located around the dam sight that are used for conventional trilateration. The 42 points on the crest of the dam are all force centering monuments mounted in concrete pillars. This makes moving the GPS antenna from monument to monument very simple and fast. The monument mounted in the pillar is a brass plug approximately 5 inches high and machined such that a female brass connector can be set down over it. The female connector has a 5/8 inch by 11 thread that can be screwed directly into the antenna.

Four GPS receivers were used on the test at Clinton Lake. The first two days were devoted to performing the relative kinematic test. For this test, two receivers were located, one each on two of the reference monuments, and two

others were used as rovers, occupying all 42 monuments on the dam during a period of approximately 3 hours. During the remainder of the test, the two receivers that had been used in the kinematic mode as rovers were now used in the relative static mode for 1-hour observation sessions. This was done to compare the kinematic results with the static results. Final results showed that the static, conventional and kinematic surveys compared at the 2-centimeter level.

FUTURE KINEMATIC TEST

Because of the favorable results obtained to date using GPS in the relative kinematic mode, further tests will be performed by the Corps of Engineers to develop this technique for routine use by the Corps surveyors in their everyday surveying. A test is being planned for July, 1988 to be held in the White Sands, New Mexico area, where good known control has been established. This test will further investigate the potential for using relative kinematic surveying for such applications as conventional traversing. Two receivers will be used in a relative kinematic mode, one receiver occupying a known control monument and the rover occupying a series of known control monuments. This will allow comparison of GPS-derived coordinates with known coordinates.

SUMMARY

The long observation time required for performing relative static surveys is offset in many cases by other capabilities and advantages offered by GPS. These are identified as follows:

a) GPS allows the determination of a 3-D vector between two monuments very precisely,

b) GPS allows the surveyor to measure long distances in a relative short period of time compared to conventional traversing methods,

c) GPS eliminates the need for line of sight between monuments, and

d) GPS is an all-weather system.

With these capabilities and the long observation time it requires, relative static GPS is feasible for establishing basic control to be used in conjunction with other surveys, but is not feasible for actually performing these other surveys.

Relative kinematic surveying offers the same advantages as relative static surveying with the added capability of reducing total project time. The major advantage of relative kinematic surveying over relative static surveying is the reduced observation time (less than 5 minutes at each monument), which allows for more monuments to be occupied during the same observation session. If the technique of using GPS in the relative kinematic mode could be made routine enough for the surveyors to use everyday, then GPS could be used to

perform more efficiently various types of surveys, such as dam monitoring. Initial tests have shown the potential for using GPS in the relative kinematic mode. Preliminary results indicate that centimeter-level vectors can be determined on a routine basis using commercially available equipment and software. The problem of losing lock on the satellite signals still needs to be addressed, but potential solutions include: multi-channel receivers tracking five or more satellites, and fast sequencing receivers tracking a sufficient number of satellites.

CONCLUSION

In many applications, it has been shown that relative static GPS is a substantial improvement over conventional survey techniques. Furthermore, preliminary tests indicate that relative kinematic GPS offers a reduction in observation time requirements while maintaining the same precision as in relative static GPS. This reduction in observation time will make GPS more beneficial to the Corps surveyors in performing their survey mission.

ACKNOWLEDGEMENTS

The author would like to express his appreciation for the work performed on the test at Clinton Lake Dam by Mr. Dale Jarvis, USAETL, Dr. Clyde Goad, Ohio State University, and the U.S. Army Corps of Engineers Kansas City District survey personnel. He would also like to thank Mr. Frank Fowler, Louisville District for his input on the GPS projects mentioned in this paper.

APPENDIX I.--REFERENCES

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REPRINT SALES SUMMARY

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In August, 1986, the U.S. Army Engineer Topographic Laboratories (USAETL) began a 3-year program to introduce the use of GPS technology to all U.S. Army Corps of Engineers Districts as a means of performing geodetic surveys. During demonstrations, GPS receivers are used in a relative static mode with observation sessions lasting from 1/2 to 1 hour, depending on the precision required. Although GPS is a much more efficient tool for performing geodetic control surveys, a means of reducing the amount of time spent at each monument would make GPS more attractive for applications such as dam monitoring. The techniques of relative kinematic GPS provide the surveyor with the capability of reducing observation time.

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